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6. AUTHOR(S)

Forrest S. Mozer, Principal Investigator
Michael A. Temerin, Assistant Research Physicist

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of California
Space Sciences Laboratory
Berkeley, CA 94720

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13. ABSTRACT *(Maximum 200 words)*

This contract supported the analysis of S3-3 satellite data and the correlation of the results with results from experiments on other spacecraft. The general purpose of these studies has been to characterize auroral electric fields and waves for their own sake because they have interesting nonlinear plasma properties, and to study the relation of these waves and fields to auroral particle acceleration. These studies have been very successful in explaining many auroral phenomena and in advancing our knowledge of auroral physics. Eighty-one publications resulting from this research have appeared in the refereed literature. Discussed in these publications are:

1) the discovery of electrostatic shocks in the auroral acceleration region, including the shocks' parallel fields that produce particle beams;
2) the discovery of double layers and solitary waves in the auroral acceleration region;
3) the discovery of electromagnetic ion cyclotron waves and their role in accelerating electrons and ions;
4) the characterization of the field-aligned currents in the auroral acceleration region;
5) the understanding of ion and electron conic generation by the observed large-amplitude waves and fields.

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Final Report for ONR contract N00014-81-C-0006

During the last nine years ONR contract N00014-81-C-0006 has supported the analysis of S3-3 satellite data and the correlation of these results with other experiments. The general purpose of studies has been to characterize auroral electric fields and waves for their own sake because they have interesting nonlinear plasma properties and to study the relation of these waves and fields to auroral particle acceleration. These studies have been very successful in explaining many auroral phenomena and in advancing our knowledge of auroral physics.

Some of the most notable discoveries during this period were those of small-amplitude double layers (Temerin et al., 1982; Mozer and Temerin, 1983; Temerin and Mozer, 1985, 1987) and electromagnetic ion cyclotron waves (Lysak and Temerin, 1983; Temerin and Lysak, 1984). The electrostatic shocks, discovered previously in the S3-3 data, were analyzed and their association with auroral particle acceleration described (Boehm and Mozer, 1981; Mozer, 1981; Temerin et al, 1981a, 1981b; Bennett et al., 1983; Kletzing et al., 1983; Temerin and Mozer, 1984; Witt, 1984; Mozer et al., 1985, Redsun et al., 1985). The large scale currents and electric fields that govern the dynamics of the auroral zone were characterized (Torbert et al.,1981; Rich et al., 1981; Cattell, 1983; Wygant et al., 1983; Wygant, 1983). A variety of other waves observed by the S3-3 satellite were characterized and their relation with currents and energetic particle precipitation described (Cattell et al., 1981; Cattell, 1981; Temerin, 1981; Cattell, 1982; Witt, 1984; Bergmann, 1985; Andre et al., 1986; Boehm et al., 1987; Roth and Hudson, 1989; Temerin and Kintner, 1989; Roth et al., 1989). The effect of the large electric fields and large amplitude waves in producing auroral particle acceleration in general and in particular in producing such phenomena as ion conics, electron conics and field-aligned electron acceleration were described in a number of papers (Temerin et al., 1981; Temerin and Mozer, 1984; Temerin, 1985; Temerin, 1986; Temerin and Roth, 1986a, 1986b; Temerin et al., 1986; Peterson et al., 1989; Roth et al., 1989; Temerin and Cravens, 1990). Other topics studied were the density of the auroral zone and and polar cap by means of the propagation properties of whistler waves (Temerin, 1984) and large plasmaspheric electric fields (Gonzalez et al., 1986). We also collaborated with the Viking experimenters, who have followed up on many of the S3-3 results (Block et al., 1987). The significance and implications of the S3-3 results were reviewed in a number of forums (Cattell.1982; Mozer et al., 1985; Mozer et al., 1987; Mozer, 1989). A bibliography of publications supported by the contract is attached to this report.

One important discovery was small-amplitude double layers (Temerin et al., 1982; Mozer and Temerin, 1983; Temerin and Mozer, 1985, 1987). These small-amplitude double layers consist of small regions of electric fields parallel to the magnetic field.Because electric fields parallel to the magnetic field are important in accelerating charged particles, these fields may be responsible for some particle acceleration that takes place in the aurora. The small-amplitude double layers are seen in regions of up-going ion beams and downward accelerated electrons where auroral acceleration processes are known to take place. These results have recently been confirmed by the Viking satellite (Bostrom et al., 1988; Koskinen et al., 1990). Our results are also important because the small-amplitude double layers are an interesting example of nonlinear plasma physics and as such have stimulated much theoretical interest (Hudson et al.,; Barnes et al., 1985; Tetreault, 1988).

Another important discovery has been oblique electromagnetic ion cyclotron waves (Lysak and Temerin, 1983; Temerin and Lysak, 1984). These waves propagate below and between the various ion gyrofrequencies. The mode is the finite frequency limit of the Alfven wave. These results have also recently been confirmed by results from Japanese satellites ISIS 1 and 2 and by the Swedish satellite Viking (Saito et al., 1987; Gustafsson et al., 1990). These waves are important because they have the highest wave energy density of any of the wave modes in the aurora and so can greatly affect the ion and electron distribution. We have applied these results to recent rocket data to show how these waves can produce the flickering aurora (Temerin et al., 1986). Also low frequency waves propagating below the ion gyrofrequencies in this mode are important in other electron and ion acceleration processes as described below. Currently we have developed a model using these waves to explain an important feature of impulsive solar flares, the enhancement of energetic Helium-3 by more than a factor of a thousand that often accompanies these flares. These results show the importance of in situ measurements of the S3-3 satellite in elucidating general astrophysical phenomena.

Electrostatic shocks are another important discovery of the S3-3 satellite. The structure, occurrence, and association of electrostatic shocks was described in a number of papers (Boehm and Mozer, 1981; Mozer, 1981; Temerin et al, 1981a, 1981b; Bennett et al., 1983; Kletzing et al., 1983; Temerin and Mozer, 1984; Witt, 1984; Mozer et al., 1985, Redsun et al., 1985).Boehm and Mozer searched for large regions of parallel electric, the so-called strong double layers that were thought to produce the parallel acceleration in the aurora.Only one possible case of such large fields was found showing that most of the auroral acceleration was probably produced by smaller parallel fields distributed over larger distances. Temerin et al. (1981a, 1981b) described the correlation of electrostatic shocks with ion and electron acceleration and described the small-scale structure of electrostatic shocks. It was shown that the potential through the shock was comparable to the energy of the upward-flowing ion beam immediately adjacent to the shock and that the shock had a polarity consistent with the so -called S-shaped or V-shaped structure.It was also shown that very strong wave electric fields in the electrostatic ion cyclotron mode and lower hybrid mode occur coincident with the large quasi-static electric fields of the shock. Bennett et al. described the occurrence of electrostatic shocks as a function of magnetic local time, altitude and magnetic latitude. Redsun showed the close association of electrostatic shocks with both ion beams and ion conics, two distinct forms of auroral ion acceleration, and also described the association of electrostatic shocks with electron acceleration. Mozer (1981) and Kletzing et al.(1983) showed that electrostatic shocks are associated with discrete auroral arcs. Witt (1984) made a theoretical model of electrostatic shocks based on the slow ion-acoustic mode.

The overall dynamics of the auroral zone is governed by the large scale currents and electric fields. Cattell (1983) described the association of the large scale currents with waves on auroral field lines. Wygant et al.(1983) showed that the polar cap potential has a response time of 2 to 3 hours to changes in the direction of the interplanetary magnetic field and that the potential due to nonreconnection processes is limited to less than 20 kV.

A variety of wave modes were discovered by the S3-3 satellite.One of the most notable of these modes was the electrostatic ion cyclotron mode. The basic generation mechanism for this mode is still under debate. The relation of field-aligned currents of electrostatic ion cyclotron waves was described by Cattell (1981). It was found that electrostatic ion cyclotron waves occur in regions of upward field-aligned current. Waves near the lower hybrid frequency with frequency structure based on multiples of the ion cyclotron frequency were also discovered in the S3-3 data. Cattell and Hudson (1982) described the excitation of the waves by ion rings in velocity space. Witt (1984) described the structure of nonlinear electrostatic ion cyclotron waves. Such waves can be a possible model for electrostatic shocks besides describing the nonlinear ion cyclotron waves previously discovered in the S3-3 data by Temerin et al (1979). Bergmann (1985), inspired by the large amplitude of electrostatic ion cyclotron waves in the S3-3 data, described the nonlinear decay of the ion cyclotron waves. Andre et al. (1986) described the generation of higher harmonics of the ion cyclotron wave by ion conic distributions in auroral acceleration regions. Roth and Hudson (1989) described the excitation of the linearly stable modes by injection of Argon beam in a multispecies plasma and discussed the effects of these modes on particle diffusion.Temerin and Kintner (1989) reviewed low-frequency turbulence on auroral field lines and in the equatorial region. They showed that some of the low-frequency turbulence is due to the propagation of electromagnetic ion cyclotron waves while another portion of it is due to static structures embedded in the plasma. These static structures often have a large electric field power at higher frequencies (above 1 kHz) implying, because of Doppler shift effects, that there are fairly large static potential structures on the scale of few meters in the auroral and polar cap plasma.Roth et al., (1989) showed that many excitation mechanisms with application to magnetospheric problems can be described as merging of two plasma eigenmodes.

All significant particle acceleration on auroral field lines is due to electric fields either in the form of waves or quasi-static structures. The parallel electric fields associated with the electrostatic shocks produce the energetic large-scale electron acceleration associated with the so-called inverted V's and discrete auroral arcs. In addition there are other acceleration processes that produce ion conics, counterstreaming and field-aligned electron beams, electron conics, and flickering aurora. A review of these acceleration processes with an emphasis on ion conics and counterstreaming electron beams was given in Temerin and Mozer (1984). It was argued that obliquely propagating waves below the hydrogen cyclotron frequency were responsible for the acceleration of in conics and counterstreaming electron

beams. Ion conic acceleration mechanisms were described by Temerin (1986) and by Temerin and Roth (1986a ,1986b). It was shown by Temerin that ion heating occurs over a large altitude range on auroral field lines and that a form of ion conic called an 'ion bowl' distribution is the natural consequence of bulk ion heating over a large altitude range. Temerin and Roth (1986) described a new mechanism of ion heating by waves below the ion gyrofrequency, such as, for instance, the electromagnetic ion cyclotron waves previously mentioned. Peterson et al. (1989) and Ball (1989) have subsequently further examined this mechanism. The production of electron conics was described by Roth et al. (1989) and by Temerin and Cravens (1990). It was found, contrary to previous suppositions, that electron conics can be produced by the acceleration of electrons by waves in a direction parallel instead of perpendicular to the magnetic field and that such acceleration can be due to electromagnetic ion cyclotron waves. The production of flickering aurora, as mentioned before, had also been shown to be due to these waves.

The research supported by the ONR contract N00014-81-C-006 and previously by N00014-75-C-0294 has been extremely productive in elucidating the mechanisms for producing waves and particle acceleration on auroral field lines. In addition several Ph. D. dissertations were supported by these contracts (Cattell, 1980; Wygant, 1983; Witt, 1984; Bergmann, 1985).

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